A. Rakholia*, A. Sugarbaker, A. Black[†], and M. Kasevich (AOSense, Inc.)
B. Saif, S. Luthcke, L. Callahan, B. Seery, L. Feinberg, J. Mather, and R. Keski-Kuha (NASA Goddard Space Flight Center)
* arakholia@aosense.com
[†]Currently affiliated with U.S. Naval Research Laboratory

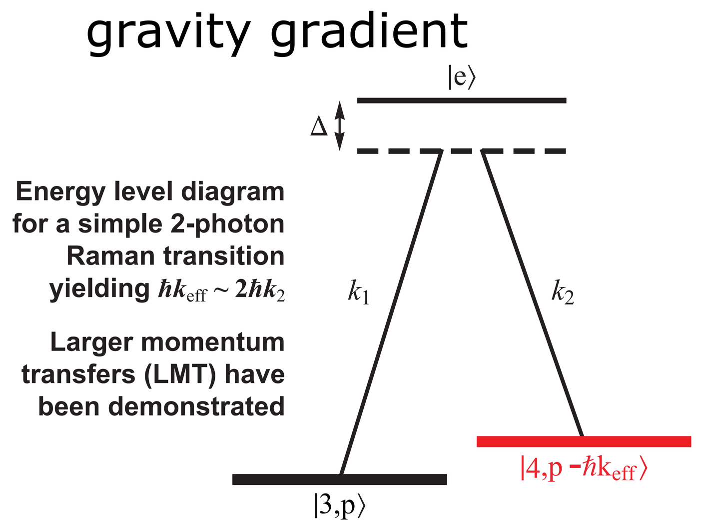
Development of an Atom Interferometer Gravity Gradiometer for Earth Sciences

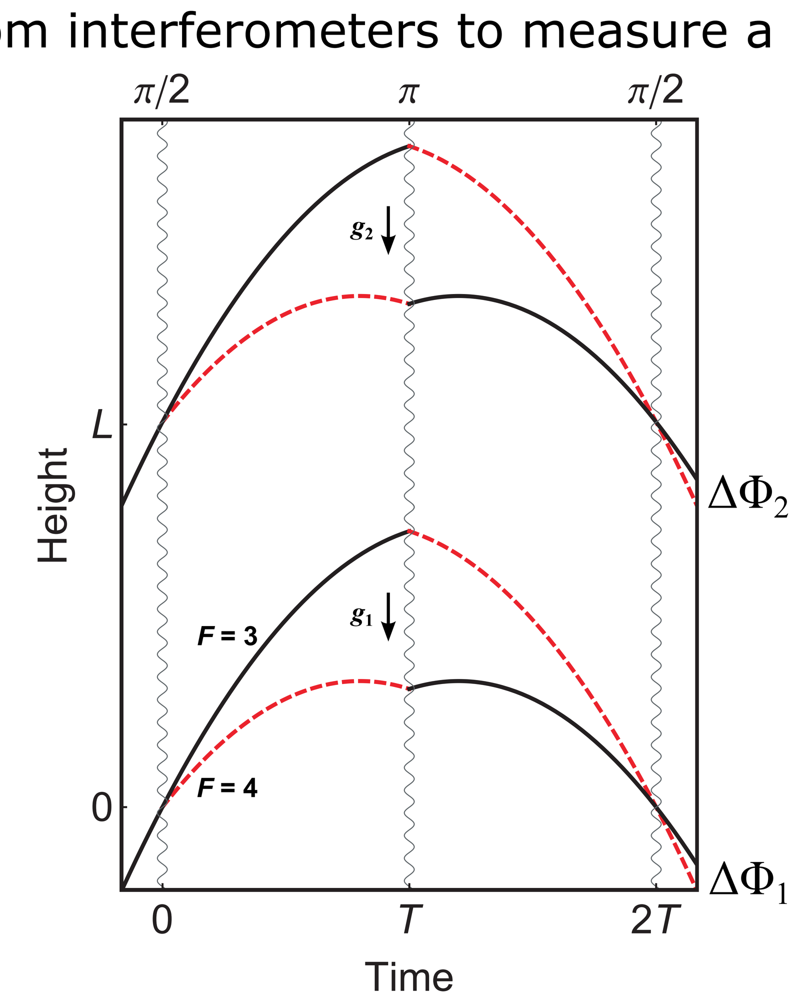
Introduction

We report progress towards a prototype atom interferometer gravity gradiometer for Earth science studies from a satellite in low Earth orbit. The terrestrial prototype has a target sensitivity of 8 x 10^{-2} E/Hz$^{1/2}$ and consists of two atom sources running simultaneous interferometers with interrogation time T = 300 ms and 12 $\hbar$k photon recoils, separated by a baseline of 2 m. By employing Raman sideband cooling and magnetic lensing, we will generate atomic ensembles with N = 10^6 atoms at a temperature of 3 nK. The sensitivity extrapolates to 7 x 10^{-5} E/Hz$^{1/2}$ in microgravity on board a satellite. Simulations derived from this sensitivity demonstrate a monthly time-variable gravity accuracy of 1 cm equivalent water height at 200 km resolution [1], yielding an improvement over GRACE by 1-2 orders of magnitude. A gravity gradiometer with this sensitivity would also benefit future planetary, lunar, and asteroidal missions.

Atom Interferometer Gravity Gradiometer

- Coherent splitting of the atom wavefunction with light pulses transfers momentum $\hbar\mathbf{k}_{\text{eff}}$ to part of the atom
- Atom follows a superposition of two spatially separated free-fall paths
- Difference in phase accrued along the two interferometer arms yields an interference pattern (fringe) at the output ports
- Phase of the output fringe is sensitive to the atom's acceleration
- Compare two spatially separated atom interferometers to measure a gravity gradient



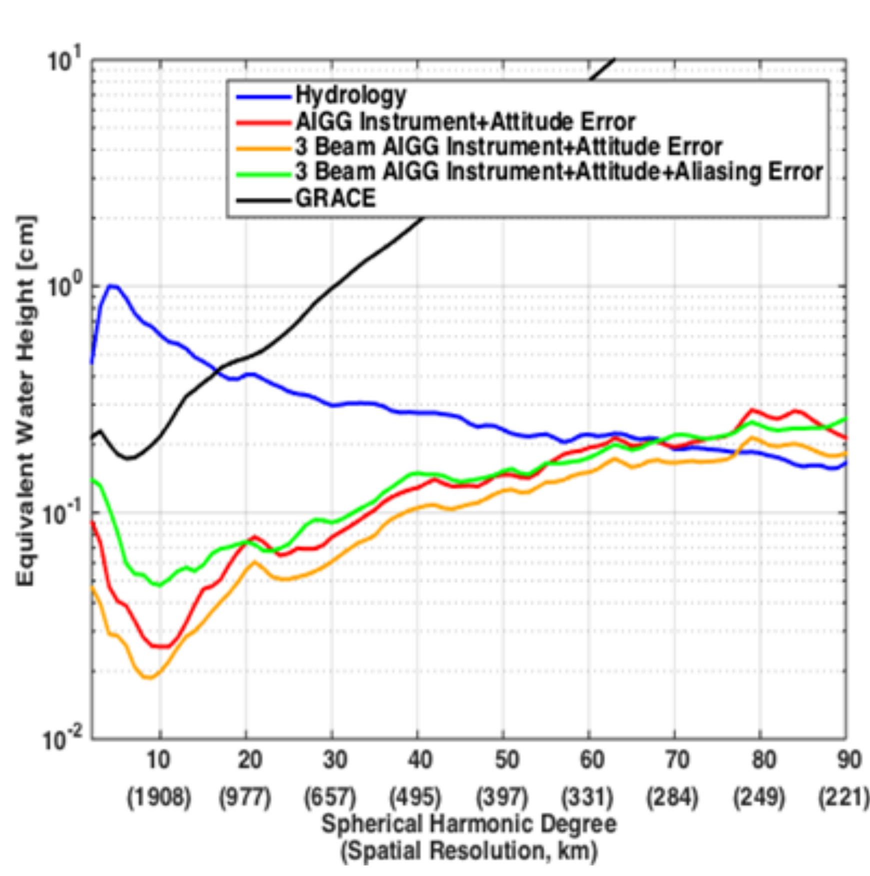


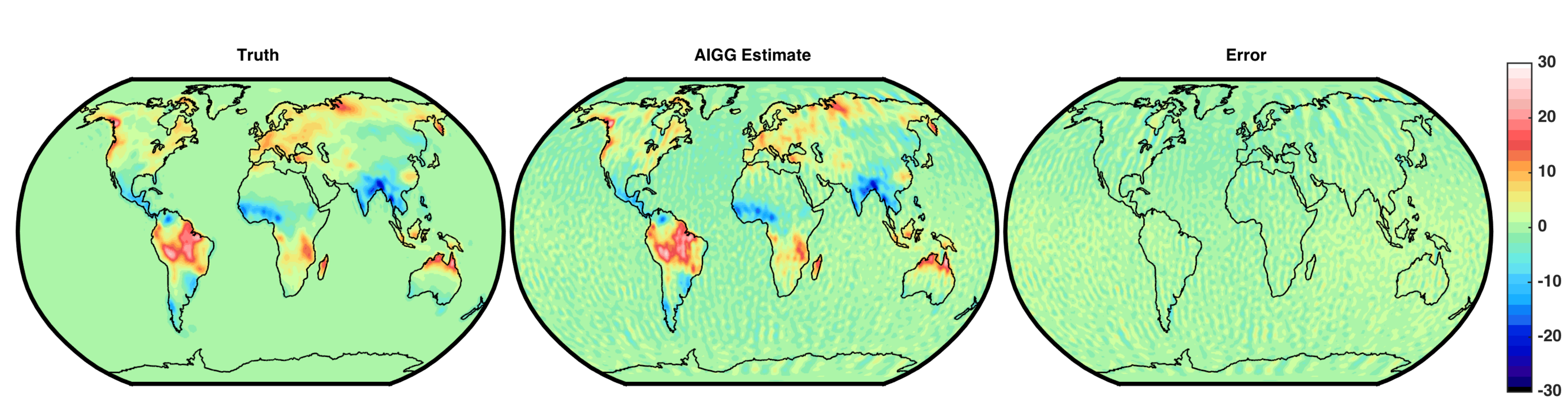
Semi-Classical Phase Shift:

$$\begin{aligned}\Delta\Phi_{GG} &= \Delta\Phi_2 - \Delta\Phi_1 \\ &= k_{\text{eff}}\, g_2 T^2 - k_{\text{eff}}\, g_1 T^2 \\ &= k_{\text{eff}} T_{zz} L\, T^2\end{aligned}$$

Simulated Error Model for Earth Time Variable Gravity Measurement

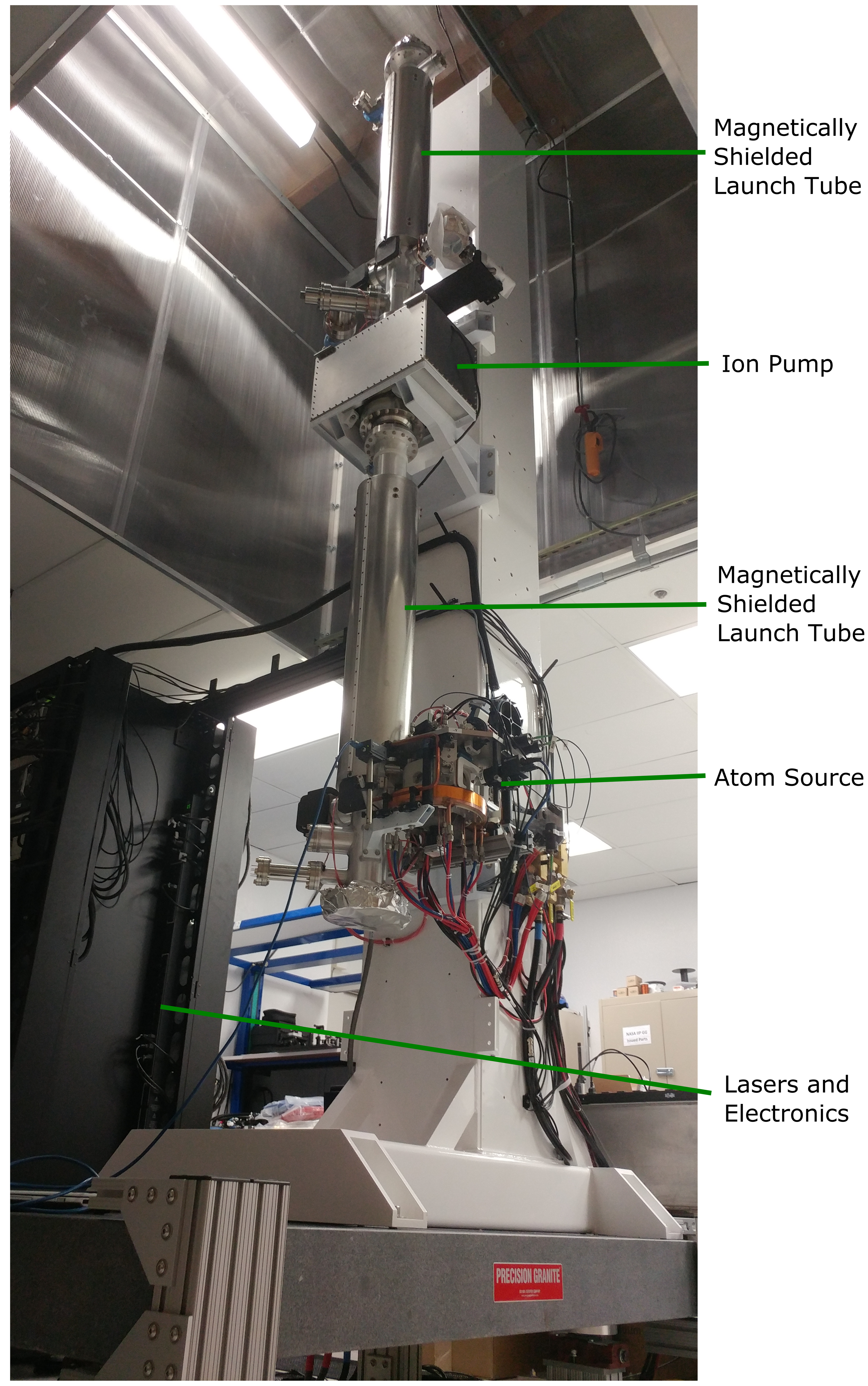
- Simulated Earth time variable gravity for 30 days in April 2009
- Simulation "Truth" incl. hydrology, glacial isostatic adjustment (GIA), ocean and atmosphere effects
- Cold atom gravity gradiometer (CAGG) simulated with T = 14 s, L = 2 m and an RMS noise of ~10^{-5} E
- Errors from satellite attitude, the CAGG instrument, and ocean and atmosphere aliasing are included



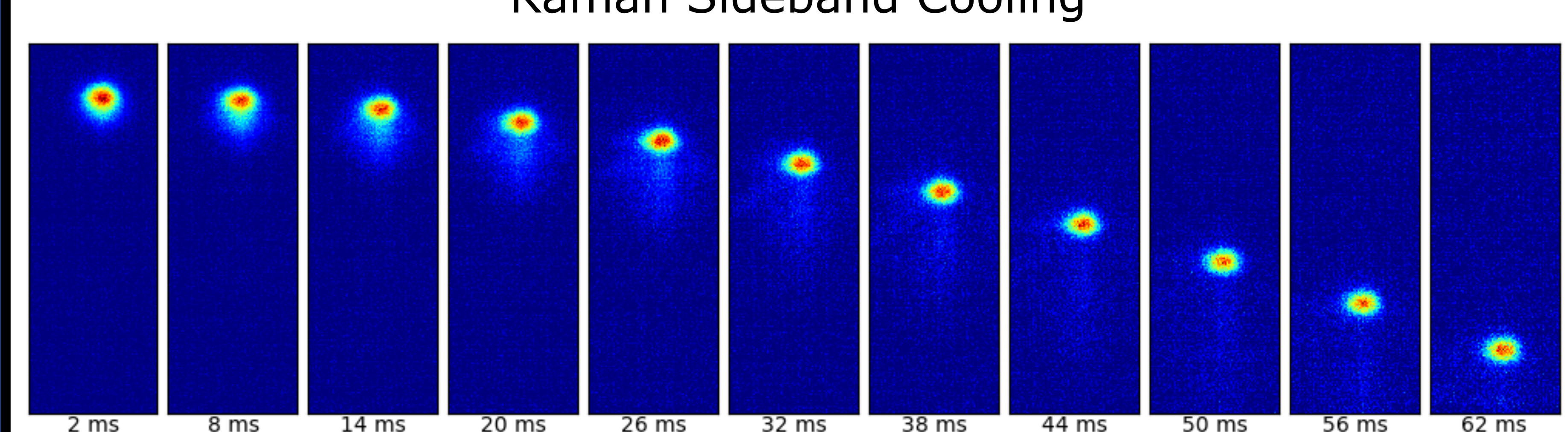


Analysis by Scott Luthcke [1]

Gravity Gradiometer for Earth Testing



Raman Sideband Cooling



T = 300 nK, N = 10^8

References and Acknowledgements

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[1] S.B. Luthcke, et al. In proceedings of the American Geophysical Union Fall Meeting, San Francisco, California, 2016.